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OFFICE OF THE SECRETARY

February 8, 2000

EX PARTE OR LATE FILED

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
445 12th St., S.W.
Washington, DC 20554

Re: ***Ex Parte* Notification**
ET Docket No. 98-153
Ultra-Wideband

Dear Ms. Salas:

This is to note that on February 8, 2000, Paul Withington of Time Domain Corporation and I made an *ex parte* presentation to Mr. John Reed, Senior Engineer in the Technical Rules Branch of the Office of Engineering and Technology, in which we provided the enclosed paper summarizing the technical literature concerning building penetration.

Should any questions arise concerning this matter, please contact me.

Respectfully,

David E. Hilliard

David E. Hilliard
Counsel for Time Domain Corporation

cc: Mr. Reed (w/enclosure)

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In-Building Attenuation Through Exterior Walls vs. Frequency

Members of Technical Staff, Time Domain Corporation

February 7, 2000

Summary

Published literature shows that exterior walls of buildings can significantly attenuate RF signals. The average attenuation cited in literature seems to fall between 10 dB and 15 dB with actual attenuations varying from 2 dB to 25 dB. The amount of attenuation is primarily dependent upon composition and thickness of the wall. The frequency of the RF emission is also a determinant, though to a lesser extent.[1]

Testing by Time Domain Corporation suggests that Ultra-Wideband (UWB) emissions experience the same attenuation as found in narrowband literature. This information is taken from unpublished data and analysis. The analysis will be presented at the Virginia Polytechnic Institute & State University's this year's Mobile & Portable Radio Research Group (MPRG) meeting in June 2nd through 4th in Blacksburg, Virginia.

These results strongly suggest that an in-building UWB system, e.g., a UWB wireless local area network, would experience much higher than 10 dB average attenuation, since the signals from many units would have to travel through more than just the external walls.

Propagation Literature Search Results

There is a vast amount of information on RF propagation through a variety of environments. Time Domain searched technical literature for in-building propagation papers, especially ones that discussed attenuation due to exterior walls of buildings and homes. The literature shows that there are significant losses from exterior walls of RF energy in the portion of the spectrum that most ultra-wideband manufacturers requested to operate in as part of the NOI comments and reply comments in FCC Docket 98-153. Further, other devices such as through-wall applications (e.g., stud finders from companies such as Zircon) would also fall into this category since they are also operated against either exterior walls, or inside of a building. While not addressed in the in-building propagation literature, this would also apply to through ground applications (e.g., ground-coupled ground penetrating radars), since the attenuation of the ground is generally significant.

Time Domain has focused on exterior walls in response to questions as to whether UWB emissions from indoor applications of UWB might cause harmful interference to receivers operated outside of buildings. In Figure 1 below, Time Domain has plotted the

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[1] Many papers dealing with this topic are listed at the end of this paper.

exterior wall loss data cited in the technical literature. Each paper presents it results slightly differently. Some listed the low and high value found at each frequency, while others listed just an average value for the losses. This is reflected in Figure 1 by the 3 different symbols. (Note, Time Domain did not calculate any of these values, they are straight from the papers.)

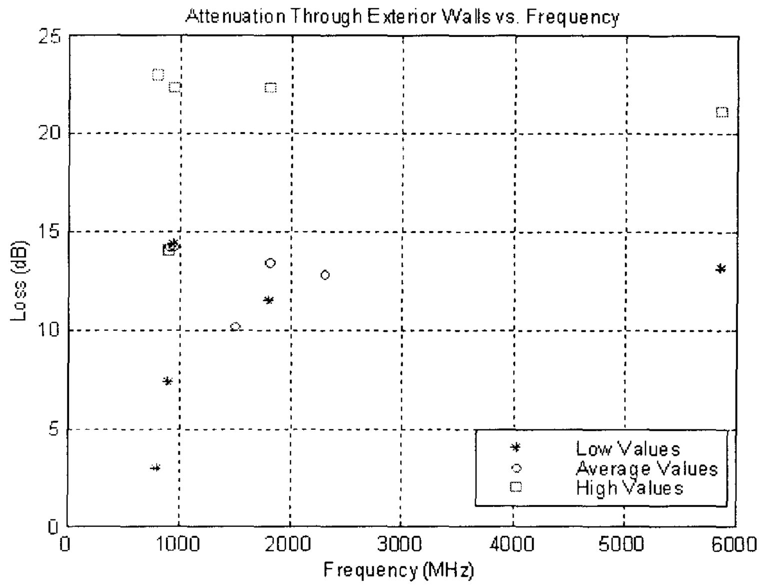

Figure 1. Attenuation Through Exterior Walls (dB) vs. Frequency (MHz). The data was taken from the first nine attached papers that discuss exterior wall losses.

Figure 9 in "Measurement of Building Penetration Into Medium Buildings at 900 and 1500 MHz," is a useful plot summarizing the different studies performed regarding "building penetration loss versus frequency" for frequencies up to 3 GHz.[2] This plot shows losses range from approximately 6 to 16 dB for frequencies greater than 1 GHz.

Thus, for frequencies above 1 GHz the exterior wall average losses appear to be between 10 to 15 dB.

Confirming UWB Test Results

Time Domain has performed propagation testing as well to aid in engineering development and creating environmental propagation models. Recently Time Domain performed propagation testing in and around five different building structures. Two were

[2] "Measurement of Building Penetration Into Medium Buildings at 900 and 1500 MHz", A. Davidson and C. Hill, IEEE Transactions on Vehicular Technology, Vol. 46, No. 1, February 1997.

schools, built in different eras with different building materials, an office building, a manufacturing building, and a dormitory. One of the many experiments performed at each of these facilities was to test the losses due to exterior walls. Table 1 below lists the general material type and the losses found from each.

The equipment used to measure these values was a device called a scanning receiver that Time Domain built specifically for UWB propagation and link studies. The signal generator associated with the scanning receiver has emissions from 1-3 GHz. The scanning receiver can not only measure the impulse response of the environment but also sends a known bit error test pattern that is used for link analyses.[3]

Table 1. Measured attenuation of materials tested by Time Domain

Materials	Attenuation
Windows	6 dB to 8 dB
Cinderblock	13 dB to 18 dB
Brick	13 dB

The exterior wall losses determined from the testing performed with the ultra-wideband scanning receiver are consistent with the results of our literature search. The data presented here is only to confirm from a few data points (5 facilities) that the losses from ultra-wideband units should be consistent with the losses found in rigorous wideband and narrowband studies.

Conclusion

Published literature on propagation of RF through external walls of buildings suggests that for frequencies above 1 GHz, the losses average 10 dB or higher.

Unpublished data from Time Domain suggests that attenuation of UWB signals by external walls is similar to the attenuation suffered by narrowband signals.

These results strongly suggest that an in-building UWB system, e.g., a UWB wireless local area network, would on average experience higher than 10 dB attenuation, since the signals from most of the units would probably have to travel through more than just the external walls.

[3] To learn more about Time Domain's scanning receiver, see "Preliminary Results from Ultra-Wideband (Impulse) Scanning Receiver" from the MILCOM 1999 Proceedings. This paper has also been included as an attachment.

Bibliography

Some papers which discuss exterior wall losses:

"5.85-GHz Radio Path Loss and Penetration Loss Measurements In and Around Homes and Trees", G. Durgin and T. S. Rappaport, IEEE Communications Letters, Vol. 2, No. 3, March 1998

"Estimating Coverage of Radio Transmission into and within Buildings at 900, 1800, and 2300 MHz", A. F. de Toldedo, A. M. D. Turkmani, and J. D. Parsons, IEEE Personal Communications, April 1998

"Measurement of Building Penetration Into Medium Buildings at 900 and 1500 MHz", A. Davidson and C. Hill, IEEE Transactions on Vehicular Technology, Vol. 46, No. 1, February 1997

"Radio Wave Penetration into Urban Buildings in Small Cells and Microcells", R. Gahleitner and E. Bonek, IEEE 44th Vehicular Technology Conference, pp. 887-891, Volume 2, 1994

"Radio transmission at 1800 MHz into, and within, multistory buildings", A. M. D. Turkmani and A. F. de Toledo, IEE Proceddings-I, Vol. 138, No. 6, December 1991

"Radio Propagation Into Buildings at 1.8 GHz", A. F. de Toledo, D. G. Lewis, and A. M. D. Turkmani, IEE Colloquium on University Research in Mobile Radio, 1990, page(s) 3/1 - 3/5

"Review on radio propagation into and within buildings", D. Molkdar, IEE Proceedings-H, Vol. 138, No. 1, February 1991

"Penetration Loss into Buildings at 900 MHz", S. Mockford and A. Turkmani, IEEE Colloquium on Propagation Factors and Interference Modeling for Mobile Radio Systems, 1998, pages 1/1 - 1/7

"On the Propagation of RF into a Building Constructed of Cinder Block Over the Frequency Range 200 MHz to 3 GHz", C. D. Taylor, S. J. Gutierrez, S. L. Langdon, and K. L. Murphy, IEEE Transactions on Electromagnetic Compatibility, Vol. 41, No. 1, February 1999

Some papers which discuss interior wall losses:

"Indoor Wideband Radio Propagation Measurement System at 1.3 GHz and 4.0 GHz", D. A. Hawbaker and T. S. Rappaport, Electronic Letters, Vo. 26, No. 21, 1990, pages 1800-1802

"Radio Propagation Measurements at 850 MHz, 1.7 GHz and 4 GHz Inside Two Dissimilar Office Buildings", D.M.J. Devasirvatham, M.J. Krain, and D. A. Rappaport, Electronics Letters, 29th March 1990, Vol. 26, No. 7, pages 445-447

"Transmission and Reflection Characteristics at Concrete Block Walls in the UHF Bands Proposed for Future PCS", W. Honcharenko and H. L. Bertoni, IEEE Transactions on Antennas and Propagation, Vol. 42, No. 2, February 1994

Preliminary Results of an Ultra-Wideband (Impulse) Scanning Receiver

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Abstract–Time modulated ultra-wideband (TM-UWB) techniques allow the transmission and fully coherent reception of RF signals with very large fractional bandwidths for a wide variety of important applications. However, traditional instrumentation (e.g., spectrum analyzers) cannot be used at meaningful distances to measure the channel response for such signals. Without such measurements it has been impossible to create channel models except in a few simple cases.

Now a TM-UWB scanning receiver has been constructed that allows precision measurement of the impulse response of the channel where measurements can be made out to the maximum communications range of the system. This versatile system not only captures ultra-wideband propagation waveforms, but information on data symbol statistics. The data collected from this measurement instrument can be used to create channel models, guide selection of locking algorithms, characterize noise, analyze error correction techniques, and eventually study geo-ranging capabilities.

Preliminary measurement results will be presented for an in-building environment. Results include the value of coherent rake combining.

I. The Problem

While it is generally recognized that frequency diversity improves communications link performance within high multipath environments, there is insufficient data to allow definitive comparisons between ultra-wideband and traditional approaches, e.g., frequency hopping and direct sequence spread spectrum.

Traditional instrumentation, such as spectrum analyzers, have limited usage for measuring ultra-wideband signals because at meaningful distances the ultra-wideband signal is below ambient noise and phase information is not available. Thus, as with much of the work done to evaluate the propagation of traditional spread spectrum signals, a special instrumentation system is required to capture ultra-wideband propagation data.

Win [1] used a synchronously triggered digital sampling oscilloscope measurement system to measure propagation within buildings, an approach that works when the ultra-wideband signal is not buried in noise. When ambient signal levels are large, the inability of an oscilloscope to synchronously trigger on the desired signal prevents data acquisition. Thus, it is impossible to use this same instrumentation approach to capture ultra-wideband signals at longer ranges in urban environments where there are large background signals, e.g., cellular and television emissions.

To overcome the limitations of both traditional instrumentation and the synchronously triggered digital sampling scope instrument, a unique measurement instrument was built using a time modulated ultra-wideband rake receiver concept.

II. Basics of TM-UWB

TM-UWB, an advanced ultra-wideband RF technology, utilizes short Gaussian monocycle pulses and related waveforms at relatively high pulse repetition frequencies. Typically, pulse durations are less than 1 ns and pulse repetition frequencies exceed 1 MHz. The interval between pulses is not fixed, but is time coded using sequences of random or pseudo-random numbers. This time hopping randomizes the signal in both time and frequency domains. Also, time hopping allows for code division channelization and acts to decorrelate in-band jammers.

Pulse position modulation is used to encode information onto the pulse train. For example, a binary modulation scheme could transmit a monocycle pulse one-quarter of a pulse width early (relative to nominal) to represent a "0" bit and one-quarter of a pulse width late to represent a "1" bit. A single bit or data symbol is typically spread over many pulses. The receiver uses a cross correlation technique (a matched filter that consists of an analog multiplication followed by an integration) to directly convert each RF monocycle into a baseband signal. The output of the correlator is an estimator of the time of arrival of the received pulse plus a noise component. Multiple correlation values can be coherently combined to combat noise.

In TM-UWB radios, processing gain is achieved through two mechanisms. The first mechanism is the low duty cycle of the signal; the correlator provides for a duty cycle processing gain, e.g., a 500 ps pulse transmitted, on average, once every 100 ns, has a duty cycle processing gain of 200 or 23 dB. The second source of processing gain is from coherent addition of correlation samples; for example, coherently combining 1000 pulses yields an additional gain of 1000 or 30 dB. Total processing gain is then the sum of the duty cycle gain and the pulse integration gains.

A more detailed description of time modulated ultra-wideband is found in [2].

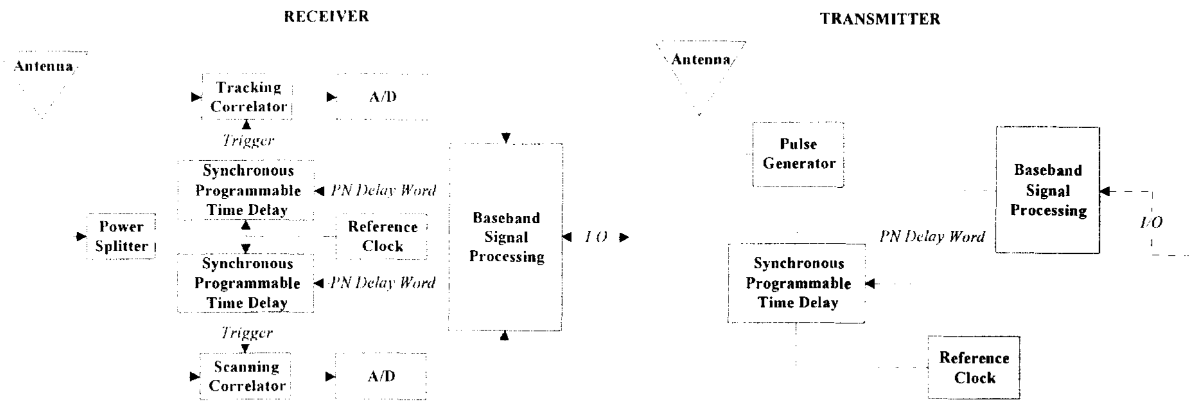

Fig. 1. Receiver and transmitter block diagram.

III. MEASUREMENT OBJECTIVES

Clearly, the duality of the frequency and time domains means that existing frequency domain propagation measurements can be translated into the time domain [3]. Unfortunately, the bandwidth of existing narrowband measurements and the loss of phase information prevents examination of sub-nanosecond scale processes. These limitations prevent the development of definitive channel models for time modulated ultra-wideband signals using narrowband data. Thus, to create useful channel models for time modulated ultra-wideband, extremely fine time resolution is an absolute requirement.

A useful channel model for time modulated ultra-wideband RF would describe:

1) Gross $1/R^n$ attenuation characteristics based on the largest received pulse;
2) The number of time resolvable pulses (paths) and their time and post-correlation amplitude distributions (time dispersion, related to delay spread); and
3) Variability of propagation paths as a function of distance moved (path attenuation due to blockage, related to coherence bandwidth and time).

In addition, it would be valuable to record time of arrival in order to estimate accuracy for a geo-ranging application. Recording characteristics of the noise would also help guide the selection of error detection and correction algorithms.

IV. THE SYSTEM

With the development of a precision, low noise synchronous programmable time delay integrated circuit [4], it is now feasible to build customized time modulated ultra-wideband propagation measurement instruments. Figure 1 shows the block diagram for the scanning receiver and its companion transmitter.

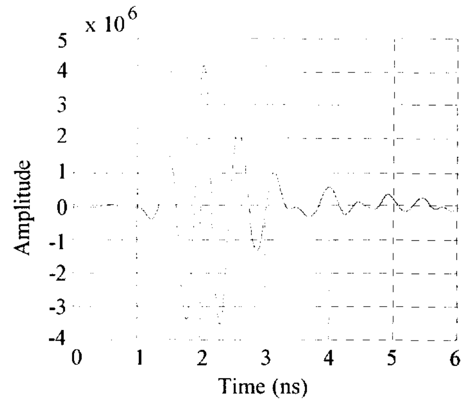

Fig. 2. Received ultra-wideband pulse. The amplitude scale is an arbitrary unit.

In this implementation, the transmitter emits a 500 ps ultra-wideband pulse at a 10 MHz pulse repetition frequency. Figure 2 show the output of the scanning receiver when it scans a single transmitted pulse. This measurement shows the filtering impact of the receive antenna, the correlation process, and that the transmitted pulse was filtered to reduce emissions below 1 GHz. The bit integration period is 128 pulses, providing a 78.125 kbps data rate link. The pseudo-random time-hopping sequence repeats once per bit period. Encoded in the data stream is a bit error test pattern of length 32768.

The receiver consists of two correlators each controlled by an independent timing system. The tracking correlator varies the phase of its internal coded template until it synchronizes with and is able to track the received pulse train. Any offset between the transmitted pulse repetition frequency and the receiver's internal pulse repetition frequency is detected as an error voltage in the correlation lock loop. This error is corrected by synthesizing a frequency offset in the pseudo-random time hopping word. This adjustment ensures the receiver's clock is within approximately 20 ps RMS of the transmitted clock.

Once the tracking correlator is synchronized and locked to the incoming signal, the scanning correlator can sample the received waveform at precise time delays relative to the tracking point. By successively increasing the time delay while sampling the waveform, a complete, time-calibrated picture of the waveform can be collected.

At the same time that waveform data is being captured, samples from the tracking correlator are also being collected. Samples from the tracking correlator represent integrated, demodulated data symbols prior to processing by the symbol decision logic. Samples from the scanning correlator and tracking correlator are collected in pairs so that events in the waveform sample set are time correlated with events in the data symbol set.

Control of the system and data storage is provided by a PC externally connected to the scanning receiver. Several parameters can be varied when capturing a waveform. The scanning correlator can dwell at a time position for a specified number of pulses, allowing the baseband signal processor to integrate samples and minimize distortion due to noise. Sample time steps as small as 3.052 ps can be specified, but more typical step sizes are around 60 ps. Time delays of up to 13 μs before or after the tracking point can be specified for start of the waveform capture.

There are two different RF front-end options for this instrument, defined by the configuration of the correlation circuits. The correlation function is implemented in a custom silicon-germanium monolithic integrated circuit [5] which has a single RF input and three independently triggered correlator circuits. One option uses a single integrated circuit for both the tracking and scanning function, providing a single RF input for both functions. The other option uses separate integrated circuits for the tracking and scanning functions, providing independent RF inputs and therefore separate antennas for tracking and scanning. Fixing the location of the tracking channel antenna creates a fixed time reference for the scanning channel, allowing the performance of antenna arrays to be estimated.

V. CAPABILITIES

The ability of the scanning receiver to capture data symbols in parallel with waveform data allows it to be used not only for propagation studies but also as a complete link budget analysis tool. A few of the primary applications are summarized here.

As a propagation tool, the scanning receiver can be used to measure the impulse response of the environment between any two locations within the communication range of the radio link. In conjunction with application specific requirements, the response data can guide the selection of signal acquisition and tracking algorithms. For environments with significant multipath effects, it allows estimation of the marginal value of additional correlators for rake receiver applications. Also, if the locations at which measurements are taken are closely spaced, i.e., the antenna is moved less than a pulse width between scans, then individual paths may be analyzed for amplitude fluctuations.

Because data capture is synchronized to always start at the same phase of the bit error test pattern, the user has *a priori* knowledge of the bit sequence and can compare expected data symbols to actual received symbols. This allows characterization of bit errors, guiding selection of error detection and correction techniques.

Symbol data captured from the tracking channel can be used to calculate the SNR for the tracking point. Because the scanning channel is time-calibrated to the tracking channel, the location of the tracking point on the scanned waveform is known. The amplitude ratio of the actual tracking point to other potential tracking points on the waveform can be used to determine the achievable SNR for all other paths. This allows the benefit of coherent (rake) combining of multiple signal paths to be estimated.

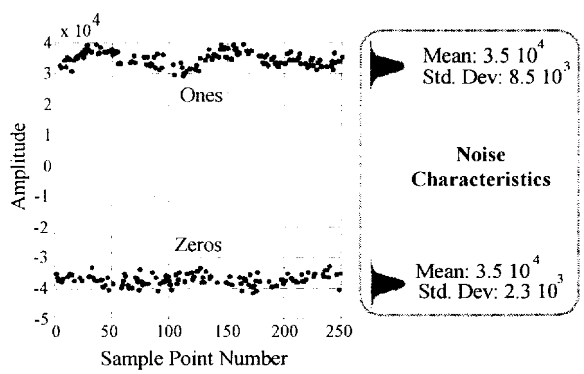

Fig. 3. Tracking channel output. (Measured at twelve feet of separation and with one intervening sheet rock and metal stud wall)

VI. PRELIMINARY RESULTS

Figure 3 is the output of the tracking correlator for a 250 point scan. In this case there is little noise in the channel, since both the zero bits mean and the ones bit mean are at least four times the standard deviation away from the zero threshold.

(The output values of the scanning receiver have not been calibrated against absolute signal values. The amplitude values shown in figure 3 and later figures are arbitrary at this time. Calibration will be accomplished in the near future.)

Each of the tracking channel samples occurs as the scanning correlator dwells on a single point in time. Thus, each tracking correlator sample is a measure of the ambient noise during the scan. In this case there is no evidence of burst noise.

Figures 4 and 5 show the impulse response measurements for two different in-building scans. The first scan is at a range of approximately 4 meters through a single wall (sheet rock over metal studs); the second at a range of 21 meters through five walls of similar construction.

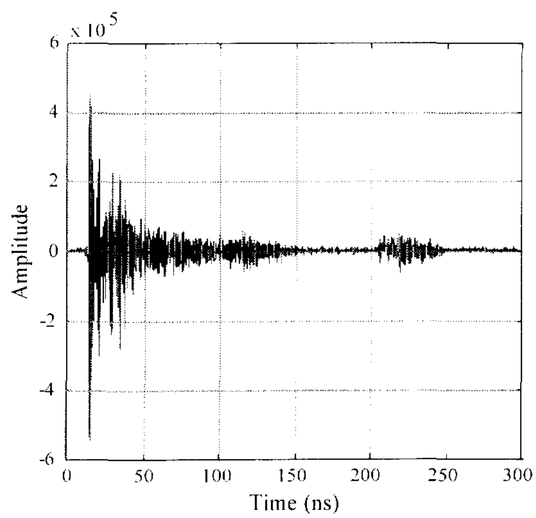

Fig. 4. Impulse response of room with 4 meters of separation and with one intervening sheet rock and metal stud wall.

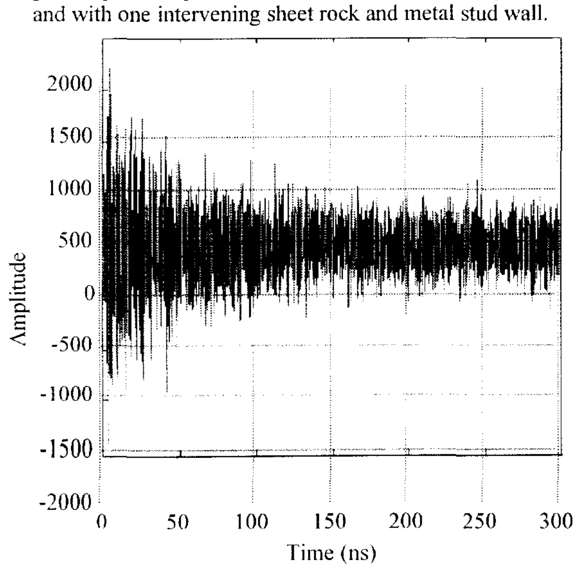

Fig. 5. Impulse response at approximately 21 meters of separation with five intervening walls.

From these scans it becomes possible to evaluate the delay spread and estimate the number and quality of signal paths. Figure 6 presents the variation in power of the three best paths at different distances. Also shown is the coherent sum of the ten largest correlations as might be obtained with a variable tap rake receiver. Figure 7 shows the time of arrival of the three best correlations (time relative to scan start time). From this figure it can be seen that sometimes the strongest correlation is not the earliest arriving signal, e.g., at the third location, the strongest correlation occurred three nanoseconds after the third best correlation.

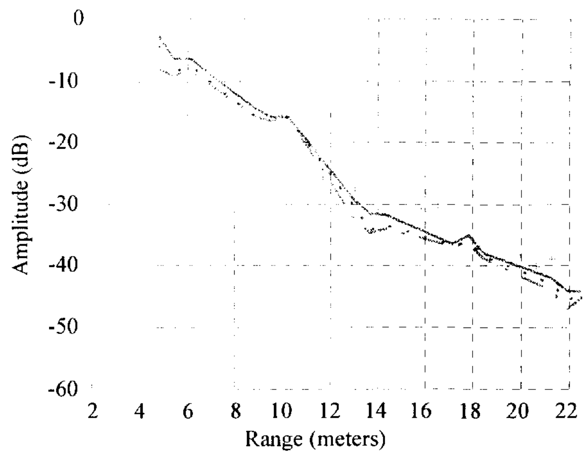

Fig. 6. The amplitude of the three largest correlations where data was taken at each location. The "+" signs indicate the coherent sum of the top ten correlation values as might be obtained from a variable tap rake receiver design.

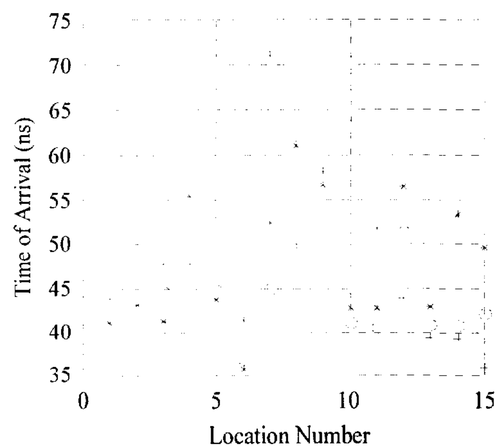

Fig. 7. Time of arrival of three largest correlations at each location where data was taken. The largest correlation is marked with "o", the second largest with "+', and the third largest with "*".

VII. OUTSTANDING ISSUES

As with all first generation instruments, there are outstanding issues. The primary outstanding issue is instrument calibration. Future efforts will be made to calibrate the instrument and then correlate the measurements with traditional instruments.

There are also analytical issues associated with proper techniques for reducing the data. Software tools are being developed to allow quick reduction of large quantities of measurements.

VIII. CONCLUSIONS

An essential stage in developing any RF system is an understanding of the channel and its impact on the link. Traditional measurement instrumentation has severe limitations when measuring ultra-wideband signals. Now, a time modulated ultra-wideband scanning receiver has been developed to not only measure the impulse response of the channel, but to evaluate symbol statistics. This valuable information can then be used to develop time modulation ultra-wideband systems that meet the specific applications requirements.

The preliminary measurements presented in this paper show the value of such an instrument. Not only is the scanning receiver useful for ultra-wideband measurements, but the data can also be used to derive narrowband channel models.

IX. REFERENCES

[1] M. Win and Robert A. Scholtz, "Energy Capture vs. Correlator Resources in Ultra-Wide Bandwidth Indoor Wireless Communications Channels" (invited paper), IEEE MILCOM 97, Monterey, CA, November 1997.

[2] R. A. Scholtz, "Multiple Access with Time-Hopping Impulse Modulation" (invited paper), MILCOM '93, Bedford, MA, Oct. 11-14, 1993.

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